Design of a Basic Vehicle-to-Vehicle Communication System for Road Safety

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Abstract
Safety while driving remains one of the significant concerns due to the growing traffic and delayed reaction to certain critical issues by drivers. In this paper, we propose the design and implementation of the simple Vehicle to Vehicle (V2V) and basic Vehicle to Infrastructure (V2I) communication system.
The system is made using a Raspberry Pi computer connected to a front unit and a camera used for detection of hazardous conditions. The rear vehicle unit designed with an ESP32 controller is used to receive messages via Zigbee and alert the driver in case of danger. Depending on the situation, the driver is supposed to slow down or perform other activities in order to avoid rear end collision.
The experiments have shown that the system can quickly react to the potentially dangerous conditions and send an alert in 0.9 to 1 seconds which is a desirable result for short range of applications. Moreover, the communication system includes a basic traffic signal control feature depending on the presence of emergency services, giving them preference to regular cars.
Therefore, the solution described can become part of the intelligent transport system in order to implement communication technologies.

Keywords: V2V Communication, V2I System, Road Safety, Embedded Systems, IoT

1. Introduction

In the past few years, the number of vehicles using road transportation services has been increasing rapidly, and the result has been a considerable increase in traffic accidents. Delayed reactions by drivers and the lack of information about other vehicles around them have resulted in numerous accidents. In most cases, the risk becomes apparent too late for any action from the driver.
As a result, the problem of communication among vehicles has been receiving increasing attention. Systems like V2V and V2I facilitate communication, thus helping the drivers get basic information about vehicles and traffic situation, which increases safety. However, most of them are based on high costs technologies and complicated configurations and therefore cannot be applied in a practical environment.
Moreover, many of the proposed solutions are presented only as a computer simulation but not realized as a hardware application. Therefore, an evident gap exists between theoretical concept and a solution to a problem that could be used in real world.

The objective of the present work is to implement a simple and efficient communication system, showing how simple interaction of vehicles could increase safety. The system will consist of low-cost hardware devices and will generate messages about risks when necessary.
The objective of this project is to demonstrate that even a primitive vehicle-to-vehicle communication system can help decrease accidents and enhance awareness of the surrounding traffic conditions without the need for sophisticated infrastructure.
Primary Achievements:

- A basic V2V communication system design using affordable hardware components.
- Creating a simple warning mechanism for nearby vehicles.
- Real-time alerts demonstration under various conditions.
- Implementation emphasis rather than mere simulation.

2. Related Work

In the last decade, a great deal of research work has been done to develop a safe driving environment based on communication among cars. In most of these works, only the exchange of some basic parameters, including the car's velocity, position, and traffic status, have been investigated. Technologies such as DSRC, as well as mobile and cellular communication technologies, have been extensively employed for this purpose. Despite their effectiveness, these techniques need costly infrastructure and cannot be employed for simple applications.
A significant portion of current research projects use simulation-based techniques to analyze traffic behavior and communication processes. Simulation provides a realistic picture of system functions and is beneficial for this purpose. On the other hand, practical problems such as limitations in hardware, communication delays, and interference are neglected.
Camera-based algorithms for obstacle detection in front of the cars, and checking driver behavior, particularly the drowsiness of drivers, are proposed by recent literature. Such techniques allow for identification of dangerous situations in an early stage. In general, however, these features have not been designed with communication among cars.
In order to address the issues related to cost and complexity, some research efforts have been made in developing simpler forms of communication that are easy to deploy and consume less energy. Such techniques are well-suited for short-distance communication, but are not extensively employed in vehicle communication systems due to time constraints.
In light of the above observations, it becomes evident that there exists a need for a solution that integrates simple communication, minimal sensing, and deployment feasibility. The current study is aimed at fulfilling this objective.

3. Methodology

The developed system will show the simplest approach to a vehicle communication system, which can be used in the identification of risk areas and sending relevant warning signals. The entire system includes two components, namely the front vehicle component and the rear vehicle component, which can transmit messages wirelessly.
The design of the front vehicle component consists of a Raspberry Pi computer connected to the camera. The front vehicle constantly records the video of the road and examines the environment around the vehicle. On this basis, it detects the existence of any object ahead and some basic motion requirements. In

addition, the state of the driver is monitored in a simple manner in order to recognize dangerous cases when the driver is not entirely focused on driving.

The design of the rear vehicle component is represented by the ESP32 microcontroller. It operates as a receiver of warning messages transmitted from the front vehicle unit and displays them in front of the driver's eyes. Thus, the driver can take corresponding measures.

Communication is carried out through ZigBee as it is cheap, easy to implement, and suitable for short-range communication. Data communication from one unit to the other is not continuous. The system only transmits data once a threat is detected. Such a system is effective in minimizing data transmission thereby being efficient.

The operations of this system start with data collection by the front unit from the camera. The data collected is used to analyze road conditions for the presence of any obstacle. Based on certain parameters, such as distance between the front unit and obstacles or even their movements, the system determines whether there is safety or danger. In case of a risky situation, a warning message is sent to the rear unit.

Receiving the warning message, the rear unit displays it in a way to allow drivers react in a timely manner hence preventing accidents, especially in cases where they are driving at short distances.

Additionally, a basic simulator has been created with the use of web and programming technologies like Python.

Working Steps

1. Capture real-time video from the front vehicle.
2. Observe road conditions and detect objects.
3. Estimate distance and movement.
4. Identify whether the situation is safe or risky.
5. Generate a warning message if required.
6. Transmit the message using ZigBee.
7. Receive the message in the rear unit.
8. Display alert to the driver.

4. Mathematical Model

In this case, a simple technique is applied for the estimation of the probability of collision of the vehicles involved. Rather than employing complicated mathematical models, simple considerations like the distance and speed are applied.

Relative Speed:

Here, the system considers the speed difference between the two vehicles involved in the operation. When the vehicle behind is traveling faster than the leading vehicle, then there is high probability of collision.

$$v_r = v_B - v_A \tag{1}$$

where:

v_b= speed of rear vehicle

v_a= speed of front vehicle

Distance Measurement:

It also measures the distance between the vehicles. The safe distance is assumed, and when the measured distance falls below that, the scenario is considered to be dangerous.

Risk Classification:

The system then categorizes the scenario in three types based on the speed difference and distance:

- **Safe -** When there is adequate distance between the vehicles.
- **Warning -** When the distance is reducing.
- **Critical -** When the vehicles are too close, and the crash may occur.

The advantage of the above process is the ease of computation involved.

5. Results And Analysis

The system was tested through a simple simulation environment, built using Python and some web technologies. The objective here was to evaluate the performance of the system and to check how effective it would be in generating warnings between the vehicles depending upon varying circumstances.

During the testing process, several cases were created, involving changes in the distance and motion of the vehicles involved. At large distances, there were no alerts, indicating that the situation was normal. However, as soon as the vehicles became relatively closer and the rear car started moving towards the front vehicle, alerts were generated.

Wherever the two cars became too close, alerts were also generated instantaneously. This proves that the system does react according to the variation in the distance and the motion of the vehicles involved. There were slight variations in the output produced each time the program was executed.

The communication between the two units was also monitored carefully. Messages sent by the front unit were correctly received by the other one with the help of ZigBee technology. There were no issues with the delay as alerts were delivered instantly.

However, the response of the system turned out to be fast enough for short-distance conditions. Despite being fairly simplistic in design, the model managed to demonstrate how the initial basic inter-vehicle communications may aid in identifying dangerous conditions.

Some minor part of the simulation included traffic light management to see how the system acts under such conditions. However, this particular feature has been explored at a fairly elementary level and will not be covered within this work.

Observation Summary:

- System responds appropriately to distance changes.
- Message generation occurs in appropriate cases.
- Vehicle communication remains stable.
- Message delays occur infrequently.
- Suitable for short-range applications.

Thus, the system demonstrates that a simplistic design allows for achieving improvements in vehicle awareness and safety.

Distance Range	Vehicle Movement	System Response
High	Low	Safe (No Alert)
Medium	Moderate	Safe
Medium	Increasing	Warning Alert
Low	High	Warning Alert
Very Low	Very High	Critical Alert

Table 1: System Response Based on Distance and Movement

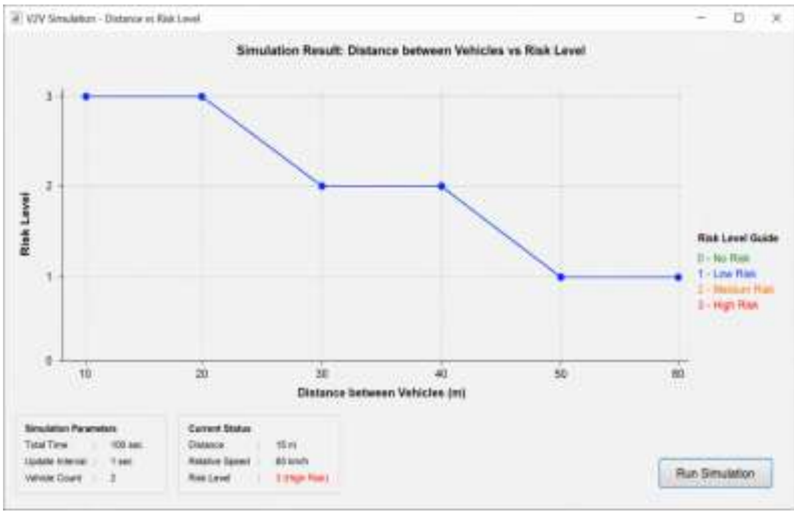

Fig. 1: Distance vs Risk Trend between vehicles

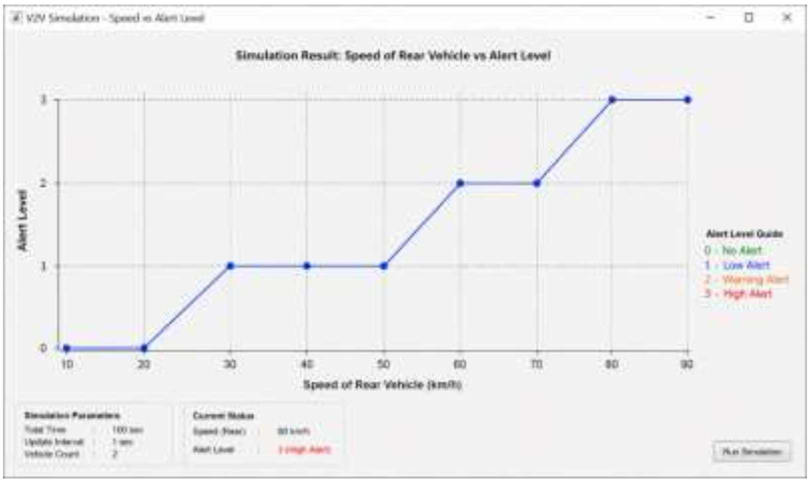

Fig. 2: Speed vs Alert between vehicles

6. Some Common Mistakes

While developing and testing the proposed system, a few common issues were observed which can affect the overall performance if not handled properly.

- **Inaccurate distance measurement:** A little miscalculation in measuring distances may cause the issuance of alerts at an inappropriate time – whether before time or even after time.
- **Lag in message transmission:** In the event of lagging in message exchange, the issued alert will not be helpful in real-time applications.
- **Improper choice of distance threshold:** Using high or extremely low thresholds for distances can cause unnecessary alerts or even missing out on some critical alerts.
- **Fluctuations in wireless transmission:** There could be some problems when using ZigBee technology for message transmission.

7. Conclusion

In this paper, an inexpensive vehicular communication system has been designed to prove how even basic communication between vehicles can increase road safety. In this system, the front unit can sense road conditions while the rear unit receives the alert messages enabling the driver to take necessary actions accordingly.

Simulation results have proven that this system can effectively detect any variations in distance or motion of the vehicles. Moreover, stable communication was recorded between the two units, along with a good response time that makes it ideal for short-range operations.

Overall, the design of this paper has tried to make things as simple as possible. Despite being basic in nature, it proves to be successful in demonstrating the idea behind vehicular communication to prevent collisions.

Future Work

While the present system works well and exhibits the principle, there are still a number of things that could be improved in the future.

The system could be put to use under real-world conditions through testing on actual cars.

Additional sensors could be employed for better precision in detecting objects around the vehicles.

A different type of technology could be employed in order to increase the communication range.

The system could be developed for use on more than two cars at once.

Some rudimentary security mechanisms could be implemented in order to guarantee safe communication between the devices.

The traffic-related aspects of the system could also be enhanced and tested in a greater variety of situations.

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